Gamma Ray Burst Afterglows and Iron K Line Emission

T. Kallman, NASA/GSFC P. Meszaros, Penn State University M. Rees, Cambridge University

GRB Iron K Lines

- Observed properties (GRB 991216):

  - Continuum Luminosity:

$$L_{cont}(t) \sim 10^{52} \mathrm{ergs}^{-1} t^{-1}$$

  - Line Luminosity near $t \sim 10^5$s:

$$L_{line} \sim 10^{45} \mathrm{ergs}^{-1}$$

  - Line Fluence: $F_{line} \sim 10^{49}$ erg

  - The spctrum detected by the Chandra ACIS is shown in Fig 1 (Piro et al. 2001)

  - A schematic for the time behavior of the line is shown in Figure 2

- Microphysics:

  - Recombination Time:

    $$t_{rec} \simeq 7 n_{11}^{-1} T_8^{0.74}$$

  - Photoionization Time

    $$t_{PI} \simeq 2 \times 10^{-7} L_{47}^{-1} R_{13}^{2} \mathrm{s}$$

  - Figure 3 shows the dependence of the timescales on gas density and distance from the GRB, and shows that the timescale for photoionization is very short for most plausible distances, while very high densities are required in order to obtain recombination timescales which are comparable.

If $t_{rec} \gg t_{burst}$ then each iron ion radiates $\sim$once. $M_{Fe} \sim 50 M_{\odot}$

- Scenarios:
  - Time Delay ($\sim 10^5$s) due to light travel time $R \sim 10^{15}$ cm
    - Dense reprocessor: $n \geq 10^{14}\mathrm{cm}^{-3} \rightarrow$ Reprocessor Mass $M \sim 10 - 100 M_\odot$
    - Low Density Reprocessor: $n \ll 10^{14}\mathrm{cm}^{-3}$ $\rightarrow$ Iron Mass $M_{Fe} \sim 10{-}100 M_\odot$ ("supra-nova scenario")
  - Time Delay ($\sim 10^5$s) due to micro-physics, e.g. recombination time $\rightarrow$ Inefficient emission. Need large iron mass.
  - Reprocessor is close to the continuum source, and time variability is associated with the dynamics of the blast wave. If so, can get large enough efficiencies to have modest enhancements of iron.

- Complicating effects: Down Comptonization allows reprocessing of gamma rays into iron lines. Pair production by gamma-gamma collisions of incident gammas with reflected X-rays changes optical depth scale, and can enhance or impede line production. Comptonization of the escaping line photons reduces overall reprocessing efficiency for narrow lines, and this effect depends on geometry (incidence and viewing angles).

- Calculations:
  - Efficiencies $\sim 10^{-3}$ are attainable, with factor $\geq$10 reduction due to the effects of Comptonization of the Fe line.
  - Requires high density ($\geq 10^{16}$cm^{-3}) and column density ($\geq 10^{25}$cm^{-2}) reminiscent of stellar envelope close to the fireball.
  - Time behavior of the line is determined by the fireball; at later times the blast wave loses energy and the line fades.

- Figure 4 shows the reprocessed spectrum. The dashed curve shows the total emitted spectrum, and the solid shows the spectrum escaping the cloud after including Comptonization.

- Figure 5 shows the same quantities but calculated for non-normal incidence (incidence angle $= 30^o$) of the continuum gammas, and illustrates that the escaping line spectrum is comparable in strength to that observed.

- Many issues are unresolved by the current observations:
  - How Broad is the line?
  - Where is the RRC? (Constrains the line formation mechanism, verifies energy scale)
  - What about Ni and Co? (Implied by supranova scenario)
  - More details about time behavior? (eg. late times...)
  - Absorption?

- Implications for Con-X
  - Need (rapid) TOO capability
  - Minimum line widths: thermal at 10^7K $\rightarrow R \sim 5000$
  - Redshift helps
  - Confusion limits affect ability to follow late time evolution.